DeltaRCWA

A nanophotonics solver for inverse design

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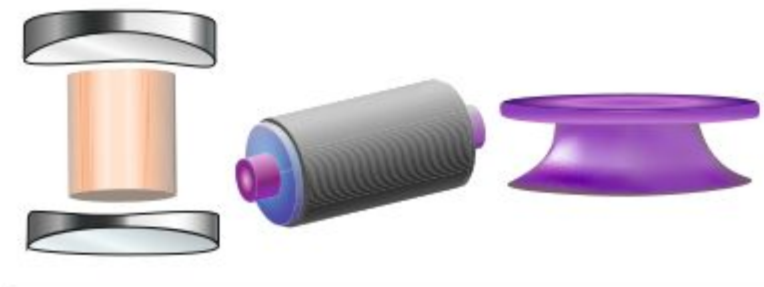
Overview

- *Background*: Photonics
- *Applications*: Metasurface Design
- *Key Concept:* Physics-Enhanced Deep Surrogates (PEDS) for PDEs
- *Conclusion*: DeltaRCWA Progress

Background: Photonics

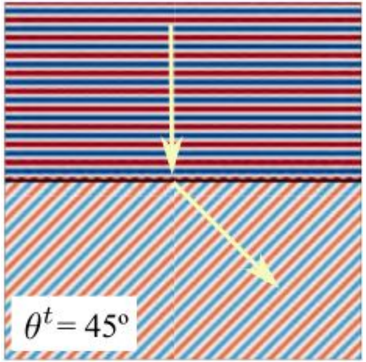
Light (photons) is transformed as it passes through materials, obeying Maxwell's equations



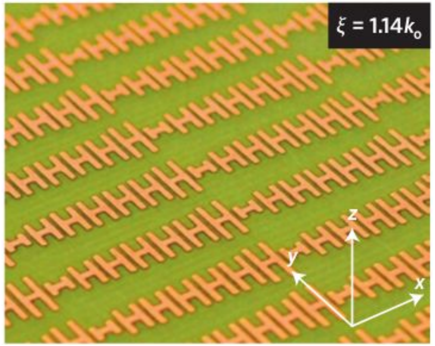
Molesky et al. (2018) "Inverse Design in Nanophotonics"

Background: Metasurfaces

Miniaturization of photonic devices leads to improved control of the reflection, transmission, polarization, and phase of light



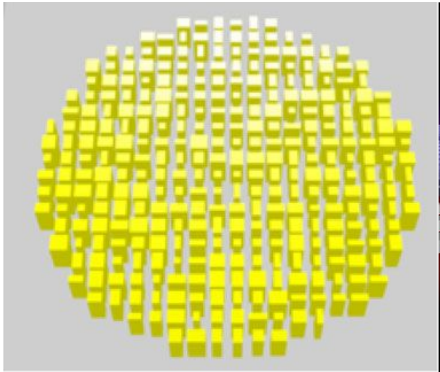
Pérez-Arancibia et al. (2018)
"Sideways adiabaticity: beyond ray optics for slowly varying metasurfaces"



Yu and Capasso (2014) "Flat Optics with Designer Metasurfaces"

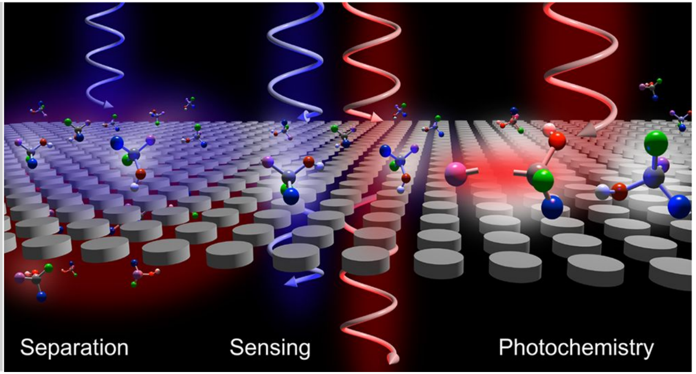
Applications: Metasurface Design

Special lenses & demultiplexers



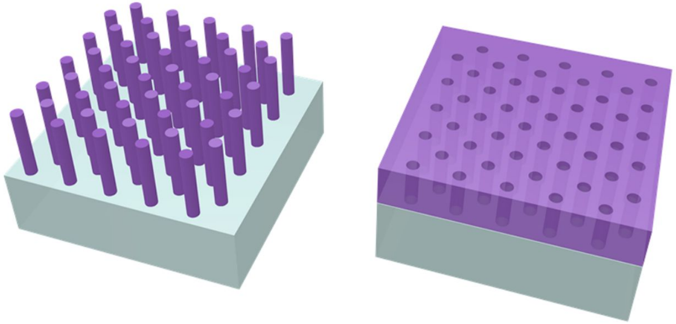
Pestourie et al. (2020)
"Active learning of deep surrogates for PDEs: application to metasurface design"

Chemistry using chiral light



Solomon et al. (2020)
"Nanophotonic Platforms for Chiral Sensing and Separation"

Light trapping in ultra-thin solar cells

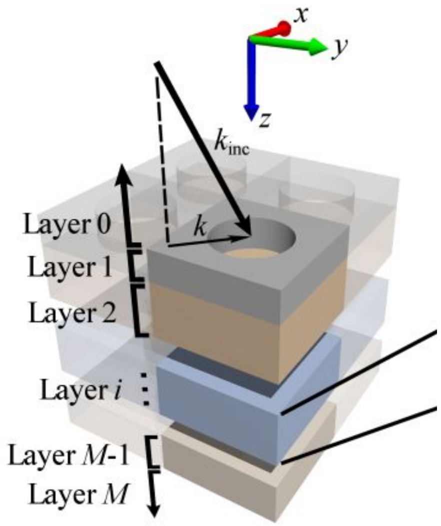


Bauser et al. (2020)
"Photonic Crystal Waveguides for >90% Light Trapping Efficiency in Luminescent Solar Concentrators"

How do we design metasurfaces by efficiently solving Maxwell’s equations?

Key Concept: Mapping 3d structures to 2d sheets

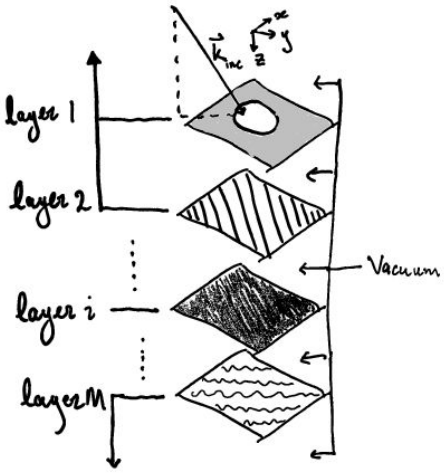
DeltaRCWA efficiently solves an approximate problem to capture key qualitative physics



Geometry coarsening

Physics-Enhanced Deep Learning

Surrogate solution

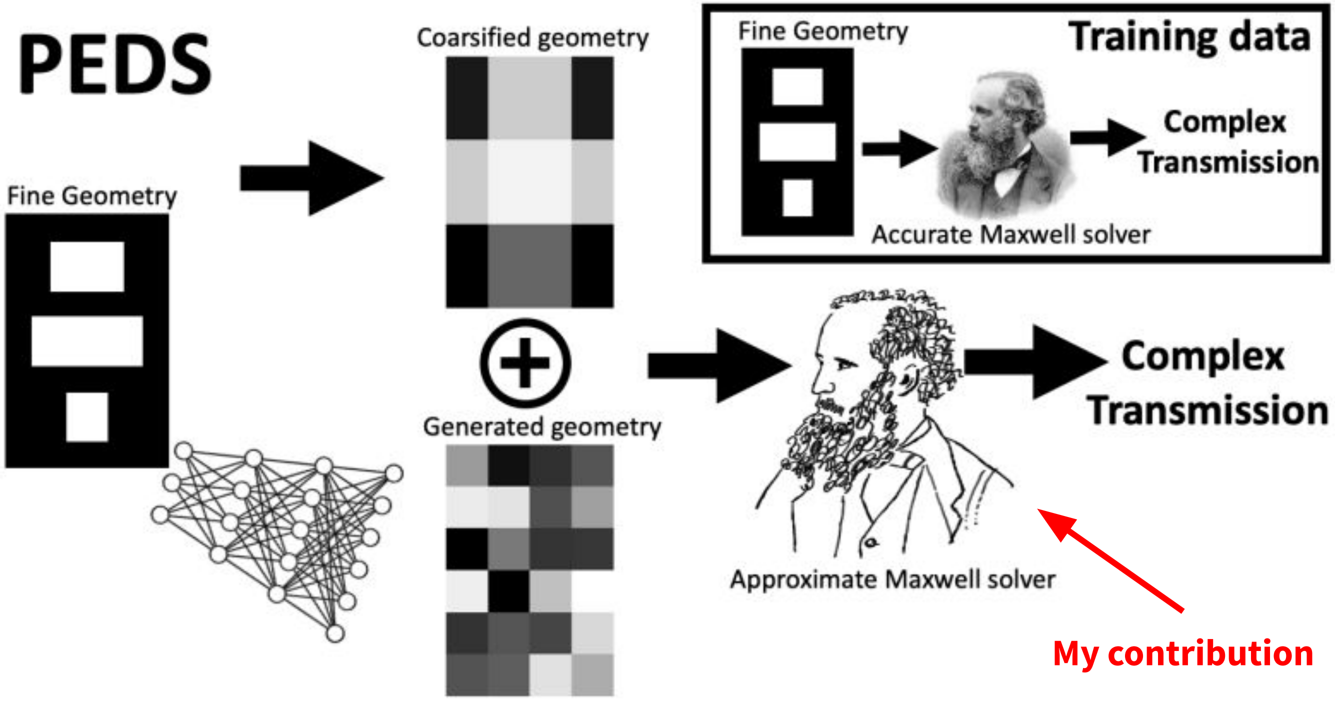


Actual metasurface

Approximate metasurface

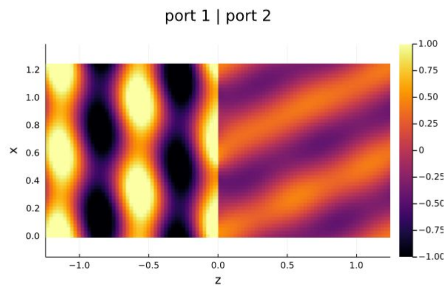
Liu and Fan (2012) “S4: A free electromagnetic solver for layered periodic structures”

Key Concept: Physics-Enhanced Deep Surrogates



Pestourie et al. (Manuscript) “Physics-enhanced deep surrogates for PDEs ”

Conclusion



Progress on DeltaRCWA

- Derived scattering matrix for full 3D simulations
- Implemented scattering matrix and Redheffer star product in a Julia package
- Explored matrix-free methods with iterative solvers to do the same

This project is still active research!

- Thorough validation of DeltaRCWA against different solvers (BIE method)
- Automatic differentiation of DeltaRCWA (Zygote.jl)
- Integration with the deep-learning framework + training with full-wave solvers (S^4)

Project URL: https://github.com/lxvm/DeltaRCWA.jl

Acknowledgements

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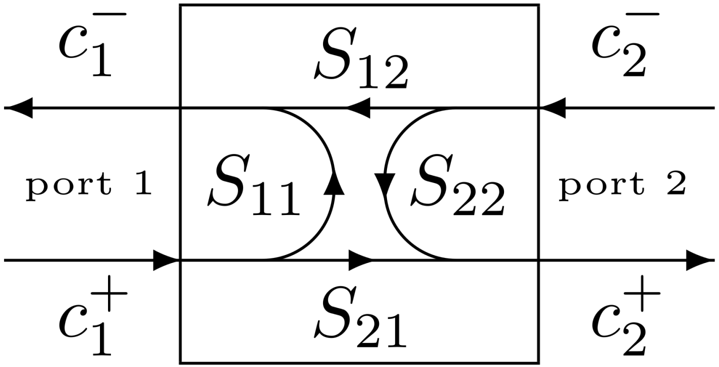
- Support: Sarah Zeichner and the Caltech MMUF Cohort

Questions!

Numerical Methods
Scattering matrices



A Generalized Sheet Transition Condition (GSTC) relates the fields on either side of the sheet in terms of the metasurface parameters

$$\hat{\mathbf{n}} \times (\mathbf{H}_{\parallel}^{i+1} - \mathbf{H}_{\parallel}^{i}) = \boldsymbol{\sigma}^{e}(\mathbf{E}_{\parallel}^{i+1} + \mathbf{E}_{\parallel}^{i})/2$$

$$-\hat{\mathbf{n}} \times (\mathbf{E}_{\parallel}^{i+1} - \mathbf{E}_{\parallel}^{i}) = \boldsymbol{\sigma}^{m}(\mathbf{H}_{\parallel}^{i+1} + \mathbf{H}_{\parallel}^{i})/2$$

Numerical Methods: Redheffer star product

Given two scattering matrices from different linear scatterers, this binary operation yields the combined scattering matrix produced by connecting some of the output channels of each scatterer to inputs of the other